1-1-1976

# Remote Sensing Technology - A Look to the Future

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Reprinted from

# Symposium on Machine Processing of Remotely Sensed Data

**June 29 - July 1, 1976**

The Laboratory for Applications of
Remote Sensing

Purdue University
West Lafayette
Indiana

IEEE Catalog No.
76CH1103-1 MPRSD

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## I. INTRODUCTION

If one is bothered by the possibility of being wrong perhaps one of the most risky things to do is to attempt to predict future directions of technology. However, in these days of extremely limited resources, good planning for development is essential to get the greatest bang for the buck spent on technology development. Such a plan must be based upon some anticipation of the direction that development will go. Thus, one must attempt to project both the potential for and direction of the future development of a technology. It is important to know at any given time what one's plan for development is, even if that plan must be revised frequently. This then, is our motivation for attempting to visualize and anticipate the results that will be presented at this and future such symposium.

But how do we begin? What can a projection be reasonably based upon? We will use two points of reference. First, we must rely on the fundamentals of the technology because of their invariance. It is unusual and certainly unexpected that events would occur which alter the fundamentals of a technology.

Second, a historical perspective of the development of the technology to this point may suggest indications as to the direction future developments will carry us. Thus, we will begin by examining these two very briefly, beginning with the fundamentals.

## II. FUNDAMENTALS

At the very core of earth resources information systems based on remote sensing is the extraction of information from the data. Modern remote sensing information extraction techniques are based on the fact that information is conveyed from the earth to the sensor in force fields and electromagnetic fields emanating from the scene and in particular through the <u>spectral</u>, <u>spatial</u>, and <u>temporal</u> <u>variations</u> of such fields. Thus, in order to derive information about the scene, one must be able to measure these field variations and relate them to scene characteristics of interest.

For example, a vertical view of an agricultural scene would be quickly identified by the relatively uniform rectangle areas defined by the agricultural fields (spatial variations) or by the color of the light emanating from the scene (spectral variations) or by the manner in which the scene changes over the course of the local growing season (temporal variations) or by a combination of all three of these.

A careful study of the ensemble of user needs suggests the necessity for both <u>identification</u> and <u>mensuration</u> capabilities in the analysis of remotely sensed data. That is to say that generally the user's requirement for information can be reduced to "What is it?" and "How much of it is there?". Thus, the data gathering and processing system must be constructed in such a way that the measurement of spatial, spectral, and temporal variations can be made to be useful not only in identifying the type of earth surface cover but also in measuring its extent. These are perhaps the most fundamental of the fundamentals of remote sensing. We shall review others as our discussion proceeds.

## III. A HISTORICAL PERSPECTIVE

The history of the development of the machine processing aspects of remote sensing is, of course, integrally tied to the development of the digital computer and the search for methods to achieve what has come to be called artificial intelligence. These fields have been under intensive study since at least the 1950's. Two branches of this development are worth noting. The oldest is that class of techniques which generally are attempting to model the manner in which human intelligence addresses a problem. The term image processing is often used when referring to these techniques. Current issues of such journals as the IEEE Transactions on Computers are filled with the results of research

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efforts of this type. Example applications areas include automatic printed and handwritten character recognition and such medical problems as the machine analysis of x-rays. So far the effort to apply this approach to earth resources problems has been very limited.

The second branch is less associated with or modelled after the manner of human intelligence. The intent has been to concentrate upon the unique capabilities of the machine for processing purposes. I refer, of course, to the so-called multispectral approach and the body of developments related to it. In this case, initial emphasis has been placed upon spectral variations rather than spatial ones as the basis for information extraction. There have been extensive efforts to apply this approach in the field of earth resources. Figure 1 sketches the major milestones of these developments. It is seen that it begins with feasibility studies in the 1964 period, passes through a research phase until about 1970, received a thorough test in 1971 and has, for the last four (4) years, been in a user application phase. Current characteristics of the effort include routine use of the technology, utilizing LANDSAT II data, involving commercially available hardware, and a current example of a practical program is the Large Area Crop Inventory Experiment (LACIE).

It would appear that this entire effort is at a turning point. Having researched, developed, and begun to apply a technology, it is now time to turn attention to the development of a second layer to this technology while at the same time continuing to further polish the existing technology and move it into the user community. This will be the first time there will have been a requirement for both research and practical applications operative at the same time.

## IV. A SYSTEMS PERSPECTIVE

Next, we must establish a generalized systems perspective in order to examine specific sub-technologies in the context of their place in the entire system. Such a generalized system overview is shown in Figure 2. A thoughtful study of this figure results in the observation that the entire system consists of three distinctly different parts. These are:

a. The Scene
b. The Sensor System
c. The Processing System

By the term scene, we refer to that part of the system which is in front of the sensor. It includes not only the earth's surface but also the atmosphere through which the energy passes both on its way to the earth's surface from the sun and on the return passage back to the sensor. Note that this is the part of the system over which there is no human control, neither on the part of the system designer before construction nor the system operator after. As a result of this, rather than system design, our major thrust here is to learn as much about the scene as possible.

The sensor system functions to gather the main body (but not all) of the data that will be available about the scene. Its design parameters must be selected so that the scene will be adequately represented by the data for the purpose of extracting the needed information. In principal, there is no reason why this part of the system cannot be directly under the control of both the designer and the operator of the system. In practice, though, this usually does not turn out to be the case. Modern sensor systems are large, complex, and expensive; as a result, new ones are designed rather infrequently, in the case of satellite sensors perhaps not much more often than once per decade. Furthermore, they must be designed to serve a broad spectrum of users and uses. As a result of this, the system designer does have design control over the sensor portion of the system but the system operator (i.e., the analyst) usually does not have operations control over it. Even in the case of the designer, however, there is little opportunity to optimize the sensor system for a given application because of the large number of applications the sensor systems must serve in order to be cost justified.

All of the remainder of the system occurring after the sensor system in the data stream, is referred to as the processing system. It is apparent that this is the portion of the system over which both the operator and the designer typically have the greatest number of choices. With due regard to costs and the economy of scale, it is possible of optimize most or all of the processing portion of this system which regard to specific applications both in the design and operation phases.

Given this brief overview of an information gathering system we will turn to a more detailed discussion of the three parts of the system just identified. This discussion will lead us to some logical conclusions about the potential for future development of this technology and the various emphases that will be necessary to realize it.

## V. THE SCENE AND ITS COMPLEXITIES

In many ways the scene portion of the system provides the greatest challenge. This is true partly because as previously noted, it is the only portion of the system not under human control. However, and much more significantly, it is by far the most dynamic and complex portion of the system. There are so many different classes of materials which are found on the earth's surface, they can be found with so many subtle and not so subtle variations due to such a large number of factors, that one must strive for a very knowledgable orderliness and discipline to see them in their proper interrelationship. A very large portion of the errors in design or operation that are made come about because of the underestimation of this complexity or misunderstanding.

For present purposes a useful mechanism for visualizing the scene in an ordered fashion is the information tree concept. See Figure 3. In this figure we see something resembling an inverted tree in which earth surface features have been listed in a taxonomic fashion. At the top are listed the more general classes of surface features; these each are then subdivided into appropriate subfeatures, and this subdivision can continue through many additional stages.

To be useful the tree must be complete in the sense that a branch must be included to account for every category in the scene. However, notice that in drawing such a tree there are many arbitrary choices which must be made, and indeed there is nothing unique about a given tree. The tree concept is intended to be useful in displaying the totality of classes of earth surface features while giving emphasis or detail to those classes which may be of special interest. Indeed, by use of this format the proper interrelationship of very detailed classes of one type can be shown relative to more general classes of another type.

For example, if one is concerned with estimating the yield likely in certain agricultural crops but the scene is likely to contain bare soil areas, cities, surface water and natural grasslands, the interrelationship of these classes can be quickly visualized in this fashion.

At this point, we must digress to review an additional important fundamental to the extraction of information from data by multispectral means. It is as follows: For the purposes of classifying data into discrete classes, it is required that (1) the class list must be exhaustive (2) the classes must be of informational value and (3) they must be separable; and furthermore these three must be simultaneously achieved.

Now conventional education and training, and indeed simple everyday human experience qualifies us at least to some extent to construct an exhaustive list of classes which are of informational value; these experiences help us very little with requirement (3). As human observers we cannot see the earth surface just as the sensor and data processing system do. We cannot say intuitively which set of classes will be spectrally separable in n dimensional space on which dates, in which spectral bands, for example. As we attempt to move to problems of greater sophistication in the years ahead, problems which take us deeper and deeper into the information tree, the need for understanding of the spectral interrelationship of the various classes of materials under the various conditions will grow. It may already be the pacing factor in the ability to successfully design such information systems.

An example of a program which is intended to increase our understanding in this area is the LACIE field measurements project. This is a joint effort between the NASA Johnson Space Center, the NASA Earth Resources Laboratory, the U.S. Department of Agriculture, the Environmental Research Institute of Michigan, Texas A&M University, Colorado State University and Purdue. The project involves the use of ground spectral measurement equipment operated in the field, helicopter-borne spectral sensors, aircraft borne sensors, as well as LANDSAT II. The overall project objectives are to quantitatively determine the temporal/spectral characteristics of wheat canopies, the soil background and the surrounding crops so as to assist LACIE and provide a calibrated, annotated, and archived spectral/temporal data set over the wavelength range from .4 to 15 micrometers for future research problems. In this fashion an extensive library of data with regard to a specific application area and geographical area is becoming available for intensive research studies. But more importantly, much additional understanding is being accumulated about the scene and its complexities.

As an illustration of exactly how such studies help, at one point in the development of this technology it was envisioned that the best way to make use of a limited amount of ground observations in a large scale survey activity was to use observations taken over a limited area to train a classifier in that area and then to extend the spectral response patterns obtained to other areas by making appropriate corrections to them based on conditions in the new areas. Field work such as the experiment described above over the last several years however, has provided convincing (if subjective) evidence that this perhaps overly simplified approach will meet with success in only a very limited number of situations. The experience gained in the field made it apparent to the researcher that the complexity of the scene is so great as to require a more sophisticated approach. Accordingly, it appears that emphasis is shifting toward scene stratification based on spectral and informational value characteristics.

Before leaving the subject of the scene and the information tree, let us consider how far we have come, i.e., how deeply into the information tree does today's technology, based upon LANDSAT, take us? A review of the literature suggests that we are able to routinely penetrate to roughly the second layer of classes indicated in the figure. Certainly, vegetation and exposed earth can reliably be distinguished between. And indeed can in some cases it is quite possible to go beyond that point on a relatively operational basis. Some advanced demonstrational or operational like programs are even supporting applications beyond this point, e.g., to forest type mapping and crop species identification.

As to the future, the potential for functioning successfully even beyond these points can, on the basis of evidence in hand, hardly be doubted. The 1971 Corn Blight Watch Experiment demonstrated, for example, that that particular crop stress condition could quite reliably be identified and broken into three levels of stress. This was possible of course because, as compared to LANDSAT II, there were a considerably larger number of spectral bands available and there was considerably greater flexibility with regard to temporal control over sampling. Even limiting ourselves to LANDSAT I/II there are many reports in the literature of experimental activities in which discrimination between more detailed classes was possible. Based on evidence such as this the potential for further development must be viewed as great.

## VI. THE SENSOR: CHARACTERIZATION OF THE SCENE BY THE DATA

Given the scene is there and observable, it is the sensor system's job to gather such data so as to adequately characterize the variations of the scene which are information bearing. Again, referring to the fundamentals, this means that the scene must be adequately represented in the data in terms of the spectral, spatial, and temporal details. Furthermore, from Figure 2 we see that ancillary data is required also to adequately characterize the scene. Let us explore the degree of scene characterization in current data sets further.

### Spectral Variations

In the earth resources field the measurement of spectral variations of the scene have received the most study. Current models for characterizing the spectral response are quite sophisticated. To illustrate, consider again using a pattern recognition device as the analysis tool. Figure 4 shows the basic block diagram of a pattern recognition system and again it consists of three parts: the physical observable (i.e., the scene); the receptor (the sensor system); and the classifier. In order to achieve a given result, i.e., a classification, the classifier must have available to it a set of measurements which adequately characterize the scene. Figure 5 illustrates the current manner in which this is done for spectral variation. Seen at the top is an example spectral response curve as a function of wavelength. Some type of mathematical sampling as carried out by a multispectral scanner containing several pass bands, is used to form a representation of this curve in an n dimensional space as shown in the lower portion of the figure. This then, is the receptors job, namely to provide the classifier with an n dimensional vector which represents in all necessary detail the physical observable.

In practice one does not sample the response curve $R(\lambda)$ at a single wavelength but rather one usually measures the amount of energy on a small band of wavelengths. Mathematically, one may represent this process as

$$\hat{R}(\lambda) \approx \sum_{n=1}^{N} C_n \, \phi_n(\lambda)$$

where $\phi_n(\lambda)$ is a function which is zero everywhere except in the pass band for n the waveband interval; it is determined entirely by the scanner design. The coefficient $C_n$ provides the measure of the amount of energy of the given $R(\lambda)$ in the waveband interval described by $\phi_n(\lambda)$; it corresponds to the displacement in the $X_n$ direction of Figure 5. The summation of such terms $C_n \, \phi_n(\lambda)$ is thus an approximation to $R(\lambda)$ and the degree to which this approximation accurately represents $R(\lambda)$ shows the degree to which the receptor is conveying all of the information in $R(\lambda)$ to the n dimensional space representation and thus to the classifier.

Figure 6 gives us an indication of the pass bands for LANDSAT I and II in relation to a typical vegetative response curve. The lower portion of the figure indicates the degree to which the true response can be reconstructed from the data. It is clear that in spite of the tremendous advancement it represented and the tremendous success it has been, LANDSAT I/II must be regarded as a very primitive first step. Not only is the visible portion of the spectrum and a small portion of the infrared conveyed only very crudely in the data, but the rest of the optical spectrum is not represented at all. Again even limiting ourselves only to spectral variations we must be standing on the threshold of tremendous advancements in the future.

### Spatial Variations

Let us turn our attention to the spatial characteristics of sensor systems. Spatial resolution is perhaps the most fought over parameter of any earth observational sensor system. This may indicate that it is the least well understood. If analysis is to be done by primarily image-oriented techniques, spatial resolution becomes a prime consideration for, in this case, it is the major information bearing attribute of the data. It conveys to the eye the spatial structure of the scene from which is possible to deduce much information about the scene.

However, if the analysis is to be done on a multispectral basis, the spatial resolution of the scene has a quite different role. It determines what informational classes can be utilized with respect to the data set. For example, data gathered over an urban scene at 100 meter IFOV would permit the analysis into such classes as industrial, commercial, high density housing, low density housing, etc. At one meter resolution on the other hand, the classes would be grass, trees, roof-tops, concrete, etc. that is, the constituent informational classes which go to make up the 100 meter informational classes. Thus, greater resolution cannot be expected, with present multispectral analysis techniques, to greatly impact classification accuracy for a given set of classes; rather it makes possible analysis of data into more detailed classes. Thus, with current multispectral processing techniques the question of what resolution largely reduces to the question of what informational classes are desired.

Greater resolution will, of course, provide greater detail about the spatial structure of the scene. Current operational machine-based analysis algorithms do not yet significantly rely upon this characteristic, however, and we shall return to this point later when dealing with the need for new processing algorithms.

Other sensor spatial characteristics are also of interest and importance. For example, the spatial sampling rate chosen is obviously an important consideration. In the interest of time and space, however, we will leave consideration of these points to another occasion.

## Temporal Variations

The importance of measuring temporal variations in a scene has long been recognized with regard to its information bearing attributes. However, much like the weather, this appears to be a case of a much discussed subject about which we have been able to do little. The problem has been that there has been less research done on temporal characteristics than their importance might suggest should be. The study of multitemporal variations and their use seems to be going through a series of three phases so common in research. Phase 1 is a period in which the initial idea looks so promising and so simple that it is clear positive and conclusive results will be obtained with the first experimentation. However, once one tries it, one finds there are some confounding factors not anticipated, thus, the second phase contains both gloom and realism. But finally, after careful thought and good hard work the potential can be realized. Initial suggestions with regard to multitemporal analysis made it look so easy because "it is obvious that" how a crop changes through the year, for example, bears information about what the crop is. Experimentation has shown, however, that because there are so many conditions that a given crop at a given time can be in, the number of permutations and combination which can be present in a crop land region in two combined observation times is very great, and a very knowledgable and systematic procedure is required to turn such data into information.

A major reason for the limitation on research results is the lack of availability of multitemporal data sets. Of course, to accummulate suitable data sets for multitemporal experimentation one must consider the time constants of the change one feels are significant. Land use change over an urban area, for example, probably has time constants of the order of months. For an agricultural area, on the other hand, the significant time constants at many times of the year are more of the order of a few days. Thus, in considering data sets for experimentation a suitable sampling rate must be chosen.

In a few instances, data sets with suitable temporal sampling rates have been collected by aircraft. The 1971 Corn Blight Watch Experiment might again be an example of this. In this case the same flightlines were overflown each 14 days. However, the number of situations dealt with by aircraft in this fashion has certainly been limited. Prior to its launch, LANDSAT I was looked upon to be potentially rich in the multitemporal aspects, given that its spectral and spacial characteristics were more limited. Indeed, observation of the earth's surface each 18 days would provide adequately for a large number of multitemporal analysis applications. Unfortunately, due to cloud cover, the only locations where LANDSAT observations tend to occur with that frequency are areas of more limited dynamic change (for example, desert regions). Furthermore, the long delay which exists between data acquisition by LANDSAT and the availability also hinders temporal studies.

Thus, while many are convinced of the importance of multitemporal data sets to future operational activities, the true potential remains undemonstrated and even largely unresearched at this time. This, by the way, would seem to be an outstanding example of a situation where an aircraft mounted sensor system would be important for research purposes; for satellite based research work we look forward to the day when 9 day and even 4 day coverage is possible to insure observation of the earth surface with a two to three week repetition rate.

Summarizing then with regard to temporal variations it would seem that like the other cases the greater portion of possible developments are still in front of us.

## Ancillary Data

There are clear indications from theory of the value of ancillary data entered into the data stream at the point indicated in Figure 2. As our experience builds with using remote sensing systems in the machine analysis mode, more and more evidence accummulates that such theoretical predictions are correct. The use of ancillary data, of course, comes in the training phase of a pattern classifier and so far the use of it has occurred in two ways.

The first is in locating and properly labeling samples from the data to be used in computing the training statistics. Here increased ancillary data results in larger numbers of training samples such that class statistics and therefore decision boundaries between classes can be more accurately located.

The second class of uses of ancillary data has to do with the identification or understanding of spectral responses observed in the training process. The system operator (analyst) during the training phase must be in position to decide upon an exhaustive list of spectrally separable classes which can be logically grouped into the desired informational classes during the post analysis processing. To successfully accomplish this task he must be able to relate observed subtle, spectral and spatial variations to the causal condition in the scene. He must therefore make use of all the objective and subjective information he may possess or acquire about the scene. This then is the machine analysis equivalent to statements by experienced photo-interpreters that the more they know about a scene the more information they can interpret from an image of the scene.

There is a new utilization of ancillary data which is now emerging. The possibility of merging into the data stream geographically arrayed ancillary information which can be incorporated into the classification feature vector directly has been suggested by a number of researchers and there are some convincing preliminary demonstrations already in the literature. An example of such information would be the elevation of individual pixels. For example, in mountainous terrain certain species only exist in certain elevation ranges; in crop land areas certain crops or certain soil types are found only within a certain range of slopes. Thus, elevation information and slope which could be derived from it are potentially useful feature vectors in the discrimination process. The list of types of information of this nature which is potentially useful is, of course, very great and much effort will be needed again to achieve all the information return possible from this added source.

## VII. ADEQUACY OF THE DATA PROCESSING PROCEDURES

So far, we have discussed the fact that the scene is a very complex physically observable part of the system and that the data provided by the sensor system must adequately characterize the variability factors in the scene which are important to the information desired. Since the processing portion of this system exists between the sensor and the user, factors related to its design and therefore to the research leading to that design must be properly influenced by both of these system elements. There are several observations which follow logically from this point of view.

### Processing Algorithms

First, the sophistication of the algorithms implemented in the preprocessing and analysis steps must be matched in some sense to a) the complexity of the data and b) the complexity of the information desired to be produced. This suggests that since increasingly complex information is being requested by the user community and since the trend of the future with regarded to data acquisition is toward more complex data (e.g., more spectral bands, greater signal to noise ratio, more spatial resolution, ancillary features, etc.) there is a need to begin to examine seriously more complex and sophisticated processing algorithms.

The potential for development is large and varied. Three important directions for this development have already been alluded to. The first is the incorporation of spatial characteristics in the multivariant (multispectral) processors. This is surely a promising area. Progress has already been reported in this area and papers to be presented in this symposium will report additional progress. The need for caution is still present with regard to the use of spatial information, however, lest the complexity and therefore the processing costs be made to rise at a rate not commensurate with the increase in information to be obtained. It is easy to think of spatially oriented analysis algorithms which would consume large quantities of computer time. Nevertheless, the promise of information return from more spatially oriented algorithms is clearly present if we are cleaver enough to see how to select them in the face of the need for computational efficiency.

The possibilities with regard to temporal variations in the scene have already been adequately explored above. Both the potential value and the pitfalls in achieving it are very real, and as indicated above, the availability of suitable data sets seems to be a pacing item for development in this area.

The third area for development of processing sophistication is suggested by the information tree discussed above. The possibility exists for carrying out classifications in steps which track to some extent the branches of this tree. There are a number of potential advantages to this. Some of them are as follows: It may be possible to eliminate certain types of illogical errors which can occur if each pixel is classified in one step to its final, most detailed class. It is quite possible for a pixel in the midst of an agricultural field to be classified into a particular tree species class, for example. If on the other hand, a preliminary classification was run in which all pixels were assigned to crop land, forest land, etc. classes, the greater simplicity of these preliminary classes might permit significantly greater classification accuracy at that level. Subsequent classification during a second pass in which the alternatives available to the classifier were conditioned upon the preliminary class for that pixel could then eliminate the possibility of a crop land pixel being assigned to a forest tree species class.

A second possibility for such conditional classification results from the fact that a more specific feature set can be designed at each decision point. That is, by doing the complete classification in stages, one can optimize the feature set used over a smaller list of possibilities, and increased accuracy of classification should result. A third possibility, again resulting from the more limited set of alternatives at a given step in the analysis suggests that a smaller feature set may be possible and as a result the net processing time can be decreased.

A fourth possibility results from the discussion above regarding new and varied types of geographically distributed ancillary data being available and for use. Again conditional classification based upon specific ancillary data widens the opportunity for higher performance of classifiers in more varied environments.

These three possible directions for future development of more sophisticated algorithms are by no means exhaustive. They were presented here merely to illustrate as graphically as possible the fact that considerable potential for future development remains. They were also chosen because there already exists preliminary indications that such developments are truly possible.

### Processor Implementation

Once the algorithms for processing have been selected, the next question which must be faced is the manner with which they are to be implemented. This question, of course, depends greatly upon the volume of data which must be processed by the given implementation before it is discarded. In order to provide a descriptive sampling of the implementation possibilities, consider the following list:

a. Services from a vendor.
b. General purpose software on a general purpose computer.

c. Special purpose software on a general purpose computer.
d. Special purpose hardware.

If only a relatively small amount of data is to be processed or if data is to be processed for only a limited period of time, the first possibility above might be considered. In this case, one has minimum commitment of initial investment and a great deal of flexibility with regard to the choice of algorithms to be used. In short, one can shop around.

Next on the scale is to utilize an existing or general purpose computer. Beyond acquiring and training the proper staff one has only to install proper software on the machine to be ready to proceed. However, if the data volume is to be larger it may be advantageous to spend more time preparing the software to achieve greater machine efficiency. For example, instead of implementing a Fortran written pattern classifier, one may wish to go to a table lookup procedure, an example of special purpose software. And finally, in this list, if a very large volume of data is to be dealt with, even greater initial expenditure may be appropriate in order to achieve the highest possible efficiency. Generally, this will require the design and construction of special purpose hardware for greatest efficiency.

It is apparent as one proceeds down this list that one trade-off involved is the initial investment required as compared to the per unit processing costs after being in operation. It is also true that to achieve the higher efficiencies of the latter alternatives one must sacrifice flexibility. In this regard, in the face of a dynamic and rapidly evolving technology, one must face the question of future obsolescence very carefully. Within the field of remote sensing it is apparent that new and more sophisticated algorithms are evolving very rapidly and a knowledge of the computer industry certainly suggests the dynamicism present in the devising of new computer hardware technologies.

Human Participation in Processing

An important element in the devising of a suitable processing system is the manner and degree of human participation in processing operations. One philosophy suggests the desirability of making the system automatic. That is, except for turning it on and off and providing maintenance functions, the goals should be largely to exclude human participation. Another alternative is to set the goals in terms of minimizing the research period and/or achieving a system with minimum processing costs. Either of these latter goals are likely to involve significant and perhaps even extensive participation of human intelligence in the analysis processing.

The question of human participation in the information extraction process goes much deeper than just whether the hardware is interactive or not. Given an interactive capability can be built into information systems with such huge data loads as these, and I believe it can, what should the man do? What tasks are best accomplished by man as compared to machine, what level of training is therefore required of the man, what operation procedures should be used in order to insure repeatability of results in the face of changing operators without sacraficing the improved system performance man's participation can provide, etc. It is proposed that this is another area about which more progress is in front than behind us.

Output Products

And finally, there is the matter of system output products. Their format, quality, timeliness, and cost must be such as to meet the user's needs. This is often a challenging question because seldom is the user in a position to state precisely what his needs are, at least not specifically. Most potential users cannot be expected to be knowledgable enough about such information systems that they will be able to correctly and quantitatively specify the geometric precision required of map outputs, the desired error rate for tabular information, the adequacy of imagery from a laser beam scanner as compared to a precision CRT, etc. And yet, if the product proves unsatisfactory to the user, it really doesn't matter whether a spacecraft multispectral scanner system was not optimally designed five years ago or everything about data collection and analysis went perfectly except that a bad choice of colors was made for the final product. The point is, the interface with the user is very important and this interface must be dealt with with the proper degree of skill, training and insite as well as with the proper range of hardware from a format, quality, timeliness and cost standpoint.

## VIII. SUMMARY

In summary then, it seems that, based upon the history and fundamentals of remote sensing we can reasonably project the potential for and value of:

1. Increasing significantly our understanding of the various variability factors of the earth surface cover,
2. More sophisticated sensor systems properly balancing improvements with regard to spectral, spatial, and temporal detail,
3. Based on these two and more sophisticated user needs, significant advancement in the complexity of processing algorithms,
4. The more knowledgable use of increased amounts of ancillary data,
5. A more informed human participation in the analysis process, and
6. A suitable array of algorithm implementations and output products to match the user needs.

The field of machine processing based remote sensing is roughly a decade old now. Ten years ago to have suggested that within a decade we would see a thing called a multispectral scanner used in conjunction with a computer to produce crop production assessments and land use maps of millions of acres in a cost effective and time effective basis would have caused at least raised eyebrows if not outright guffaws in most circles. I see no reason why at a meeting such as this ten years from now we cannot be viewing results which would be equally incredible to us today, and I, for one, look forward with excitement to the development of the second layer of machine processing technology.

| | Major Thrust | Data Collection | Data Processing | Applications |
|---|---|---|---|---|
| 1964 | Feasibility Studies | Multispectral Cameras<br>DK-2 Laboratory | Photo Interpretation of Spatial Patterns | Laboratory Spectral Responses |
| 1965 | | Scanner System Definition | | |
| 1966 | Definition of Approach | A/C Scanner | Multiband level slicing<br>Multivariant Pattern Recognition | Crop Classification (5 square mile) |
| | | Slow Scan Field Instrument | | |
| 1967 | Development of Approach over increasing | | | |
| 1968 | ·Areas<br>·Disciplines<br>·Techniques | | Data Registration<br>Feature Selection | Soil Classification<br>Water Quality and Forest Classification |
| 1969 | | Apollo IX | Sample Classification | Satellite Crop and Geologic Classification |
| 1970 | | | Clustering<br>Data Compression | Crop Yield Work |
| 1971 | Test of Technology | Quasi-operational system | | Corn Blight Watch |
| 1972 | Program Broadening User Community Contact | ERTS-1<br>Fast Scan Field Instrument | | Tests for many disciplines-5000 sq.mi. |
| 1973 | | Skylab | Geometric Correction<br>Multitemporal Analysis | |
| 1974 | | | Education Materials | |
| 1975 | | LANDSAT-II | Commercial Hardware | |
| 1976 | Routine Technology Use | | | LACIE |

Figure 1. Milestones in the Multispectral Analysis Approach

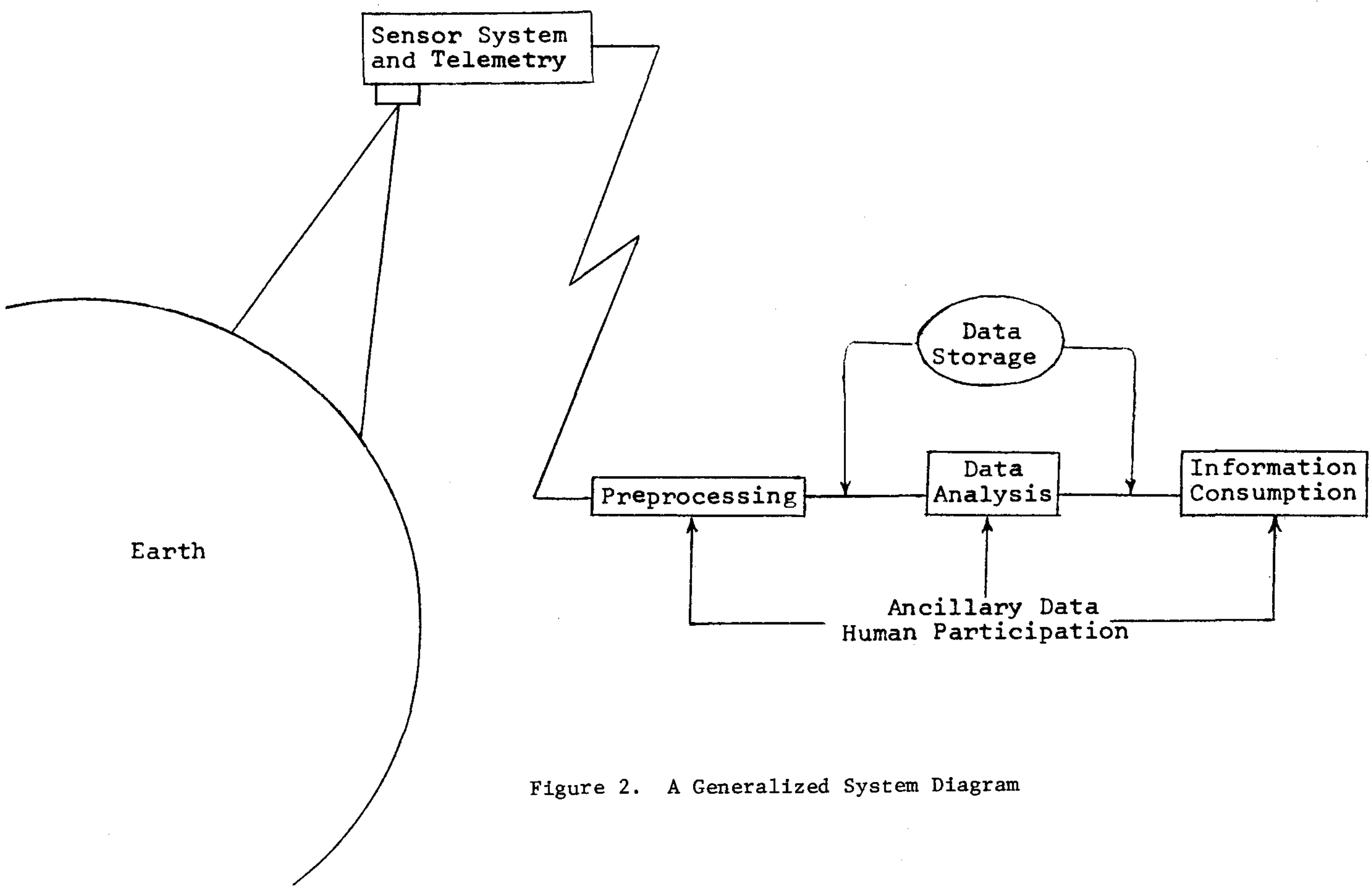



Figure 2. A Generalized System Diagram

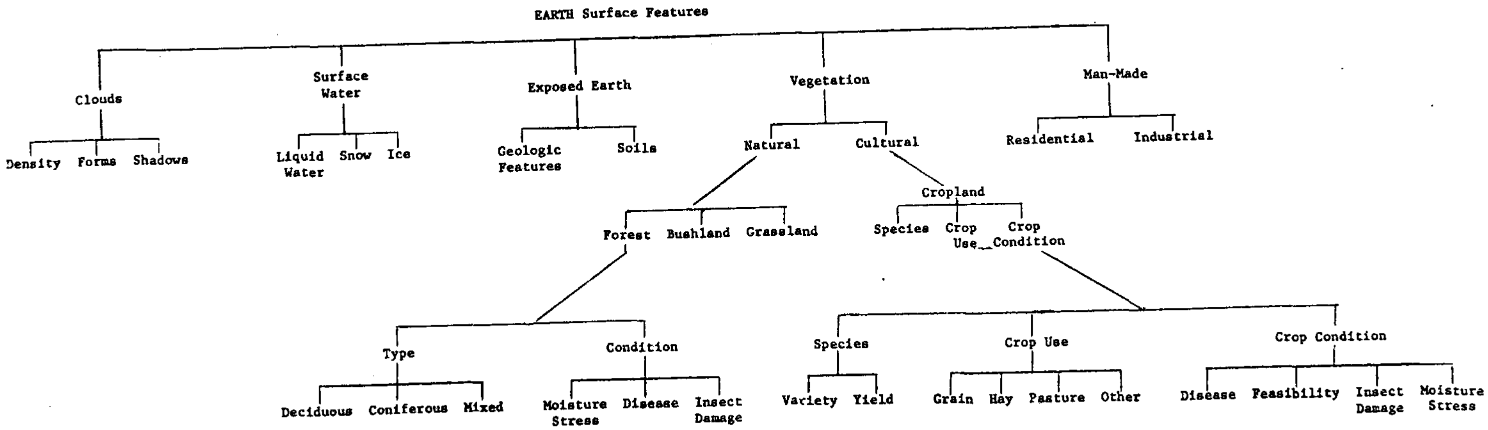



Figure 3. An Earth Resources Information Tree

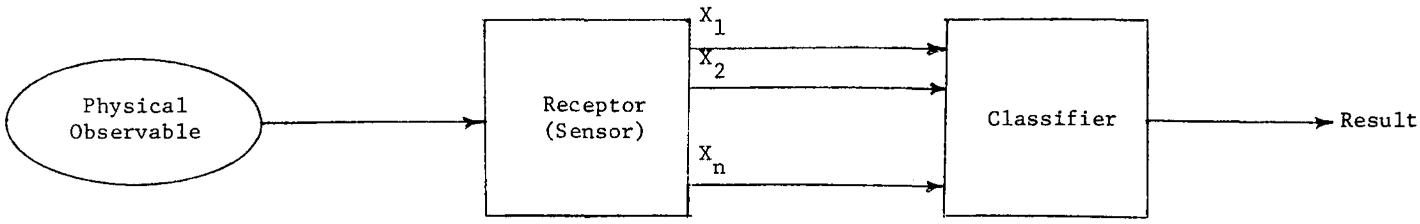
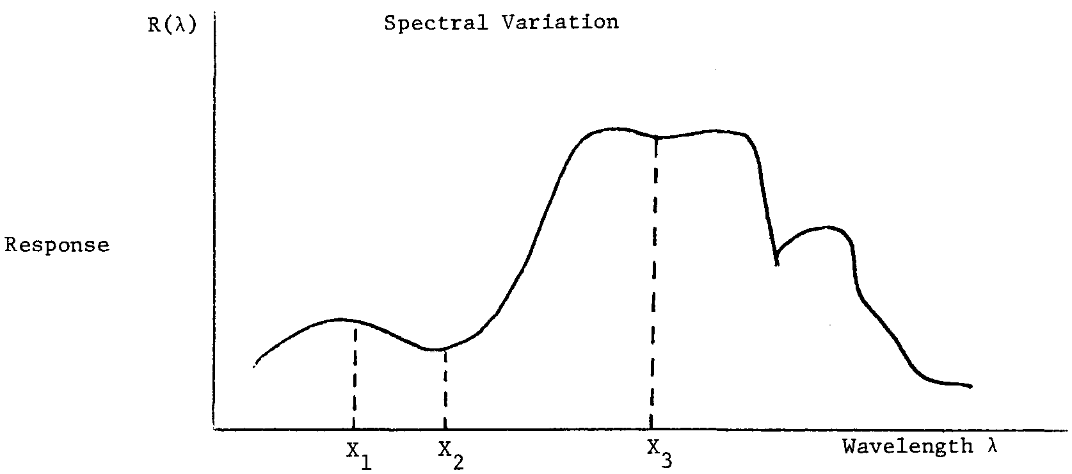



Figure 4. Organization of a Pattern Recognition System



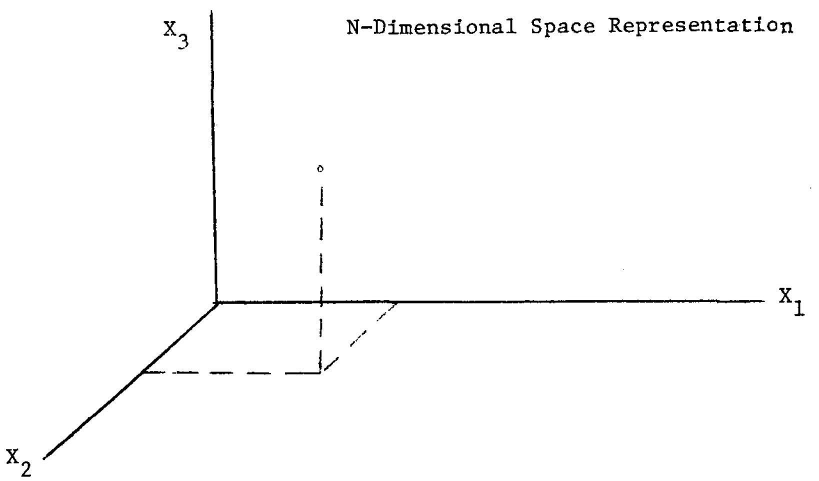




Figure 5. The Receptor's Job: Provide an n-Dimensional Vector Representation of the Spectral Response Function

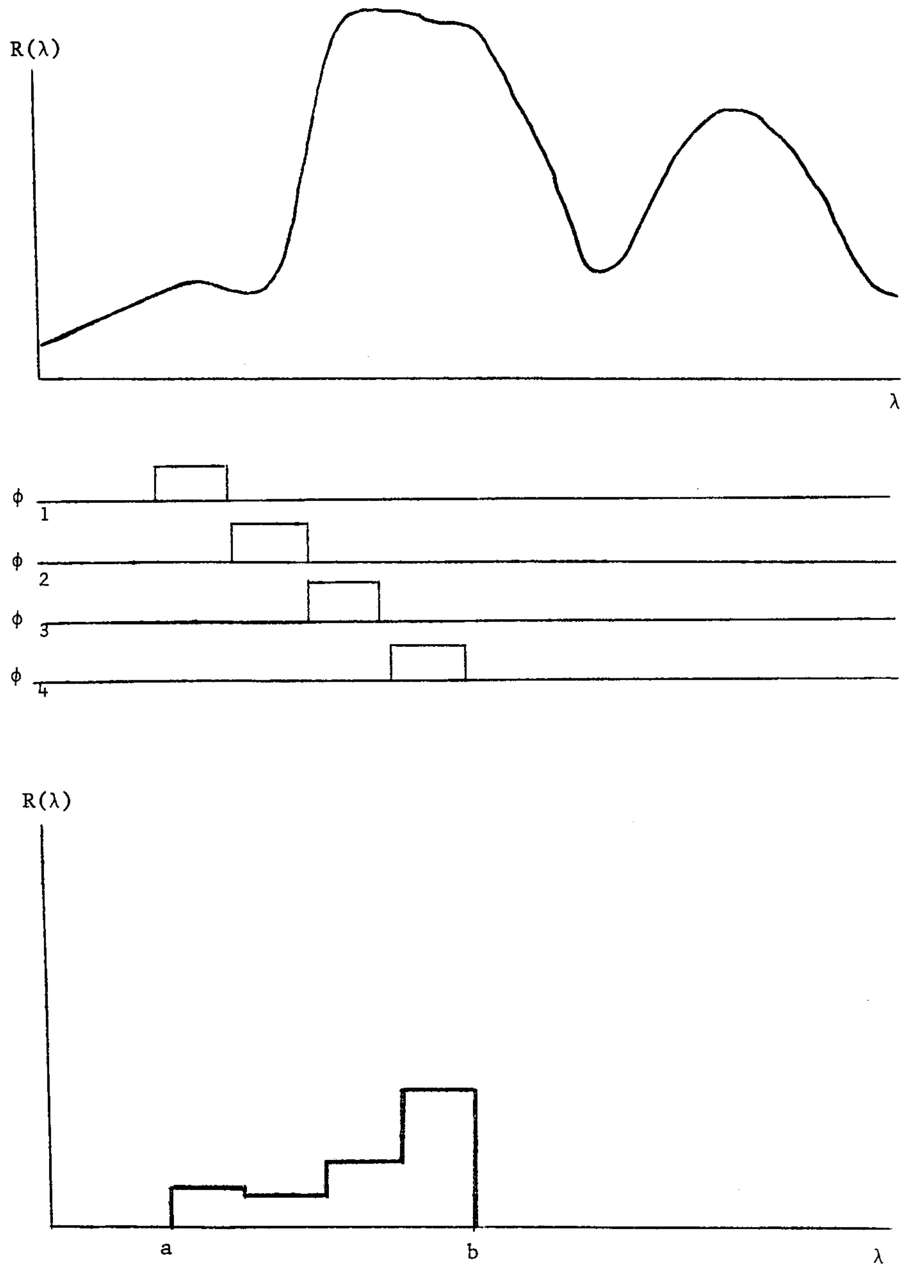



Figure 6. The LANDSAT-I/II Approximation